Chapter 6
Structural Requirements

Section 600.0 Scope

Sec. 600.1 General: All buildings and structures, covered by these Regulations and all parts thereof, shall be capable of resisting all loads required by "The Building Code" and, in addition, all loads prescribed in this chapter, without exceeding the prescribed allowable stresses.

Section 601.0 Classes of Loads

Sec. 601.1 Class 1 Loads - reflect the probable effects of flooding on structures which are waterproofed (W1 or W2). These loads shall be calculated in complete accordance with this Chapter and shall include all water, impact, and soil loads specified herein.

Sec. 601.2 Class 2 Loads - reflect the probable effects of flooding on structures which include internal flooding as a means of structural protection and which shall be so flooded in accordance with Chapter 8. These loads shall be calculated in accordance with this Chapter except that only hydrodynamic and impact loads must be considered when the interior and exterior water levels are equal.

Sec. 601.3 Class 3 Loads - apply to fully enclosed spaces which are to be flooded with floodwater internally by automatic means and to partially enclosed or external spaces. For such internal flooding, Class 3 loads shall coincide with those of Class 2. For partially exposed spaces, however, any dependent or supporting structural components shall be designed for Class 1 or 2 loads if they are also structural components of any adjacent enclosed space, whichever is required; isolated or freestanding columns or walls shall meet all criteria of 612.2.3.

Section 602.0 Water Loads

Sec. 602.1 Types: Water loads, as defined herein, are loads or pressures on surfaces of the buildings and structures caused and induced by the presence of floodwaters. These loads are of two basic types: hydrostatic and hydrodynamic.

Sec. 602.2 Hydrostatic Loads: Hydrostatic loads are those caused by water either above or below the ground surface, free or confined, which is either stagnant or moves at very low velocities, or up to five feet per second. These loads are equal to thee product of the water pressure multiplied by the surface area on which the pressure acts. The pressure at any point is equal to the product of the unit weight of water (62.5 pounds per cubic foot) multiplied by the height of water above the point or by the height to which confined water would rise if free to do so. Hydrostatic pressures at any point are equal in all directions and always act perpendicular to the surface on which they are applied. For the purpose of these Regulations, hydrostatic loads are subdivided into the following types:

> **Sec. 602.2.1 Vertical Loads:** These are loads acting vertically downward on horizontal or inclined surfaces of buildings or structures, such as roofs, decks or floors, and walls caused by the weight of floodwaters above them.
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> **Sec. 602.2.2 Lateral Loads:** Lateral hydrostatic loads are those which act in a horizontal direction, against vertical or inclined surfaces, both above and below the ground surface and tend to cause lateral displacement and overturning of the building, structure, or parts thereof.
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> **Sec. 602.2.3 Uplift:** Uplift loads are those which act in a vertically upward direction on the underside of horizontal or sloping surfaces of buildings or structures, such as basement slabs, footings, floors, decks, roofs, and overhangs. Hydrostatic loads acting on inclined, rounded, or irregular surfaces may be resolved into vertical or uplift loads and lateral loads based on the geometry of the surfaces and the distribution of hydrostatic pressures.

Sec. 602.3 Hydrodynamic Loads: Hydrodynamic loads, for the purpose of these Regulations, are those induced on buildings or structures by the flow of floodwater moving at moderate or high velocity around the buildings or structures or parts thereof, above ground level. Such loads may occur below the ground level when openings or conduits exist which allow free flow of floodwaters. Hydrodynamic loads are basically of the lateral type and relate to direct impact loads by the moving mass of water, and to drag forces as the water flows around the obstruction. Where application of hydrodynamic loads is required, the loads shall be computed or estimated by recognized and authoritative methods. Methods for evaluating water velocities and related dynamic effects are beyond the scope of these Regulations, but shall be subject to review and approval by the Building Official.

Sec. 602.3.1 Conversion to Equivalent Hydrostatic Loads: For the purpose of these Regulations and for cases when water velocities do not exceed 10 feet per second, dynamic effects of the moving water may be converted into equivalent hydrostatic loads by increasing the elevation of the RFD for design purposes by an equivalent surcharge depth, dh, on the headwater side and above the ground level only, equal to:

$$dh=\frac{aV^2}{2g}$$, where

V is the average velocity of the water in feet per second; g is the acceleration of gravity, 32.2 feet per second per second;a is the coefficient of drag or shape factor. (The value of a, unless otherwise evaluated, shall not be less than 1.25.)

The equivalent surcharge depth dh shall be added to the RFD design depth and the resultant pressures applied to, and uniformly distributed across, the vertical projected area of the building or structure which is perpendicular to the flow. Surfaces parallel to the flow or surfaces wetted by the tailwater shall be considered subject to hydrostatic pressures for depths to the RFD only.

Sec. 602.4 Intensity of Loads:

Sec. 602.4.1 Vertical Loads: Full intensity of hydrostatic pressures caused by a depth of water to the level of the RFD applied over all surfaces involved, both above and below ground level, except that for surfaces exposed to free water, the design depth shall be increased by one foot.

Sec. 602.4.2 Lateral Loads: Full intensity of hydrostatic pressures caused by a depth of water to the level of the RFD applied over all surfaces involved, both above and below ground level, except that for surfaces exposed to free water, the design depth shall be increased by one foot.

Sec. 602.4.3 Uplift: Full intensity of hydrostatic pressures caused by a depth of water to the level of the RFD acting on all surfaces involved, unless provisions are made to reduce uplift intensities as permitted in 611.0.

Sec. 602.4.4 Hydrodynamic Loads: Hydrodynamic loads, regardless of method of evaluation, shall be applied at full intensity over all above ground surfaces between the ground level and the RFD.

Sec. 602.5 Applicability: For the purpose of these Regulations, hydrostatic loads shall be used in the design of buildings and structures exposed to water loads from stagnant floodwaters, for conditions when water velocities do not exceed five feet per second, and for buildings and structures or parts thereof not exposed or subject to flowing water. For buildings and structures, or parts thereof, which are exposed and subject to flowing water having velocities greater than five feet per second, hydrostatic and hydrodynamic loads shall apply.

Section 603.0 Impact Loads

Sec. 603.1 Types: For the purpose of these Regulations, impact loads are those which result from floating debris, ice, and any floatable object or mass carried by floodwaters striking against buildings and structures or parts thereof. These loads are of three basic types: normal, special, and extreme.

Sec. 603.1.1 Normal Impact Loads: Normal impact loads are those which relate to isolated occurrences of logs, ice blocks, or floatable objects of normally encountered sizes striking buildings or parts thereof.

Sec. 603.1.2 Special Impact Loads: Special impact loads are those which relate to large conglomerates of floatable objects, such as broken up ice floats and accumulation of floating debris, either striking or resting against a building, structure, or parts thereof.

Sec. 603.1.3 Extreme Impact Loads: Extreme impact loads are those which relate to large floatable objects and masses such as runaway barges or collapsed buildings and structures, striking the building, structure, or component under consideration.

Sec. 603.2 Applicability: Impact loads shall be considered in the design of buildings, structures, and parts thereof as stipulated below:

Sec. 603.2.1 Normal Impact Loads: A concentrated load acting horizontally at the RFD or at any point below it, equal to the impact force, produced by a 1,000-pound mass traveling at the velocity of the floodwater and acting on a one square foot surface of the structure.

Sec. 603.2.2 Special Impact Loads: Where special impact loads are likely to occur, such loads shall be considered in the design of buildings, structures, or parts thereof. Unless a rational and detailed analysis is made and submitted for approval by the Building Official, the intensity of load shall be taken as 100 pounds per foot acting horizontally over a one foot wide horizontal strip at the RFD or at any level below it. Where natural or artificial barriers exist which would effectively prevent these special impact loads from occurring, the loads may be ignored in the design.

Sec. 602.2.3 Extreme Impact Loads: It is considered impractical to design buildings having adequate strength for resisting extreme impact loads. Accordingly, expect for special cases when exposure to these loads is highly probable and the resulting damages are extremely severe, no allowances for these loads need be made in the design.

Section 604.0 Soil Loads

Sec. 604.1 Applicability: Full consideration shall be given in the design of buildings, structures, and parts thereof, to the loads or pressures resulting from the presence of soils against or over the structure. Loads or pressures shall be computed in accordance with accepted engineering practice, giving full consideration to the effects that the presence of floodwater, above or within the soil, has on loads and pressures. When expansive soils are present, the Building Official may require that special provisions be made in foundation and wall design and construction to safeguard against damage due to this expansiveness. The Building Official may require a special investigation and report to provide these design and construction criteria.

Section 605.0 Hurricane and Tidal Wave Loads

Sec. 605.1 Applicability: Coverage of loads caused by flooding related to hurricanes, tidal waves, and other similar natural events is beyond the scope of these Regulations and no specific or detailed treatment is provided. Concepts and requirements of these Regulations may be used as a guide in developing suitable provisions for flood proofing of buildings exposed to flooding from these sources. FEMAs "Construction Manual" for design and construction criteria for coastal structures, NFIP regulations and other guidance is available for reference use.

Section 606.0 Loading Conditions

Sec. 606.1 Applicability: Buildings and structures, covered by these Regulations, and all parts thereof, shall be designed for all loads and loading conditions required by "The Building Code" for the prevalent state of loading when the structure is not subject to flood loads. In a separate analysis, the effects of flood related loads and loading conditions shall be calculated. Maximum values of loads and member stresses shall then be computed under the combined effects of the normal loads required by "The Building Code" and those of flood related loads. The buildings, structures, and all structural members or components thereof shall be capable of resisting these maximum loads and stresses without exceeding the prescribed allowable stresses.

Section 607.0 Combined Loads

Sec. 607.1 Applicability: All loads stipulated in "The Building Code" and all flood related loads shall be applied on the structure and on structural components, alone and in combination, in such a manner that the combined effect will result in maximum loads and stresses on the structure and members. Loads required by "The Building Code" shall be used in combination with flood related loads defined in this chapter to the extent and subject to the exceptions stated below.

(1) **Dead Load.** Use at full intensity.

(2) **Live Load.** Use at reduced intensity as provided in "The Building Code" for design of columns, piers, walls, foundations, trusses, beams, and flat slabs. Live loads on floors at or below the RFD and particularly on basement slabs, shall not be used if their omission results in greater loading or stresses on such floors. Similarly, for storage tanks, pools, bins, silos, and other similar structures designed to contain and store materials, which may be full or empty when a flood occurs, both conditions shall be investigated in combination with flood related loads of the containing structure being full or empty.

(3) **Snow Load.** Use at full intensity.

(4) **Wind Load.** Use at full intensity as required in "The Building Code" on areas of the building and structure above the RFD.

(5) **Earthquake Load.** Combined earthquake and flood related loads need not be considered.

Section 608.0 Allowable Stresses

Sec. 608.1 Applicability: Allowable stresses for all materials shall be as stipulated in "The Building Code." Except as otherwise permitted by "The Building Code," only basic allowable stresses shall be used under flood related loads or combined loads, and those allowable stresses shall in no way be increased or permitted to be used in an "overstress" condition.

Section 609.0 Allowable Soil Pressures

Sec. 609.1 Applicability: Under flood conditions, the bearing capacity of submerged soils is affected and reduced by the buoyancy effect of the water on the soil. For foundations of buildings and structures covered by these Regulations, the bearing capacity of soils shall be evaluated by a recognized acceptable method. Expansive soils should be investigated with special care. Soils which lose all bearing capacity when saturated, or become "liquified," shall not be used for supporting foundations. If a detailed soils analysis and investigation is not made, and if bearing capacities of the soils are not evaluated as required above, allowable soil pressures permitted in "The Building Code" may be used, provided those values are reduced _ percent. (This reduction should be determined for each locality and soil type by the Building Official.)

Section 610.0 Stability

Sec. 610.1 Overturning: All buildings and structures covered by these Regulations and all parts or elements thereof shall be proportioned to provide a minimum factor of safety of 1.50 against failure by sliding or

overturning when subjected to flood related loads or combined loads defined under 607.0. The required stability shall be provided by the normal resistive loads allowed by "The Building Code," such as frictional resistance between the foundations and the soil, passive earth pressure, batter and vertical piles and permanent anchors which may be provided. For the purpose of providing stability, only the dead load shall be considered effective. No use shall be made of any resistance, either as weight or frictional or passive, from soils which could be removed or displaced by excavation, scour or other causes. Similarly, no use shall be made of frictional resistance between the foundation and the underlying soil in the case of structures supported on piles.

Sec. 610.2 Flotation: The building or structure, and all appurtenances or components thereof not rigidly anchored to the structure, shall have enough weight (deadload) to resist the full or reduced hydrostatic pressures and uplift from floodwater at the RFD with a factor of safety of 1.33. For provisions governing reduced uplift intensities, see 611.0. In cases when it is not practical to provide the required factor of safety against flotation by weight alone, the difference shall be made up by providing dependable and permanent anchors that meet the approval of the Building Official. Elements which depend on anchorage to other portions of the structure shall be anchored to a portion or portions of the structure which has the required factor of safety against flotation from all contributing elements subject to uplift. Apportionment of uplift and resisting forces shall be made by a recognized method of structural analysis in accordance with accepted engineering practice.

Sec. 610.3 Anchorage: Any building and structure as a whole, which lacks adequate weight and mass to provide the required factors of safety against overturning, sliding, and flotation, shall be dependably and permanently anchored to the ground and preferably to underlying sound rock formations. In addition, all elements of a building or structure, such as walls, flood slabs, girders, beams, columns, and other members shall be dependably connected or anchored to form an adequate structural system to support the individual members and all the applied loads. Provision of adequate anchorage is also essential and required for all tanks and vessels, sealed conduits and pipes, lined pits and sumps, and all similar structures which have negligible weight of their own. (See also 1101.4, Underground Storage Tanks)

Section 611.0 Reduction of Uplift Pressures

Sec. 611.1 General: Uplift forces, in conjunction with lateral hydrostatic forces, constitute the most adverse flood related loading on buildings and structures and elements thereof. Their combined effect determines to a major extent the requirements for weight and anchorage of a structure as a whole to assure its stability against flotation, sliding, and overturning. When uplift forces are applied to structural elements of a building or structure, such as footings, walls, and particularly basement slabs, they generally constitute the critical loading on such elements. In the interest of providing economical solutions to the basic problem of structurally flood proofing buildings and structures, it is permissible under these Regulations to make provisions for effectively reducing uplift forces acting under the structure. The plans and design data submitted to thee Building Official for approval as required by 205.0, shall show complete and detailed procedures, assumptions, analyses and design information, and specific provisions to be incorporated in the work for accomplishing the proposed reduction in uplift. Data and design procedures shall be based on recognized and acceptable methods of foundation drainage and waterproofing. Such provisions shall include, but are not limited to, the following items, used alone or in combination, as conditions will dictate.

Sec. 611.2 Impervious Cutoffs: Impervious cutoffs are barriers installed below the ground line and externally to the perimeter of the building or structure for the purpose of decreasing seepage quantities and/or reducing exit gradients. Such cutoffs must, in all cases where floodwaters will rise above the ground level, be connected by suitable impervious blankets or membranes to the walls of the building or structure. Cutoffs may consist of interlocking steel sheeting, compacted barrier or impervious soil, grouted or injected cutoffs, impervious wall of interconnected concrete piles or panels, and similar seepage barriers, used alone or in combination.

Sec. 611.3 Foundation Drainage: Where impervious cutoffs are provided or where suitable foundation conditions exist, effective drainage and relief of uplift pressures under buildings and structures can be achieved. These foundation materials must be free-draining and have the desired degree of permeability. For the purpose of these Regulations, foundation drainage is intended to consist of the provision of drainage blankets, trenches, and in all cases, drain tiles or perforated drain pipes adjacent to footings and under floor slabs. Other methods of foundation drainage, such as by means of sumps, well points, or deep wells can be used for special applications. Drain pipes shall discharge into a sump or suitable collection structure, where the water is collected and ejected by sump pumps.

Sec. 611.4 Sumps and Pumps: Spacing, sizing, and determination of depth of sumps shall be consistent with and correlated to the intended drainage system, the estimated amount of seepage and drainage yield.

Section 612.0 Requirements for Other Flood Proofing Methods

Sec. 612.1 Methods: A building shall be considered as being completely flood proofed if the lowest elevation of all space(s) within the building perimeter including basement is above the RFD as achieved by:

(1) building on natural terrain beyond the limits of the base flood, on natural undisturbed ground,

(2) building on fill,

(3) building on piles and or columns,

(4) protection by dikes, levees and/or flood walls.

These methods may be used alone or in combination to achieve the required degree of flood proofing. Data and design procedures shall, in all cases, be based on recognized and acceptable methods of the applicable disciplines involved, and the following additional requirements.

Sec. 612.2 Flood Proofing by Elevating the Building:

Sec. 612.2.1 Natural Terrain: In addition to the requirements of "The Building Code," the building shall be located not less than ____ feet back from the line of incidence of the base flood on the ground. Assuming flood water at the level of the RFD, foundation design shall take into consideration the effects of soil saturation on the performance of the foundation, and the effects of flood water on slope stability shall be investigated. Normal access to the building shall be by direct connections with areas above the RFD and all utility service lines shall be designed and constructed as required to protect the building and/or its components from damage or failure during a flooding event to the RFD.

Sec. 612.2.2 Building on Fill: The building and all parts thereof may be constructed above the RFD on an earth fill. Filling a flood hazard area within a designated floodway shall not be permitted unless effects are mitigated and community variance is approved. Prior to placement of any fill or embankment materials, the area upon which fill is to be placed, including a five-foot strip measured horizontally beyond and contiguous to the toe line of the fill, shall be cleared of standing trees and snags, stumps, brush, down timber, logs and other growth, and all objects including structures on and above the ground surface or partially buried. The area shall be stripped of topsoil and all other material which is considered unsuitable by the Building Official as foundation material. All combustible and noncombustible materials and debris from the clearing, grubbing, and stripping operations shall be removed from the proposed fill area and disposed of at locations above the RFD and/or in the manner approved by the Building Official. Fill material shall be of a selected type, preferably granular and free-draining and placed in compacted layers which are tested for compaction density according to ASTM D698 (Standard Proctor Density). Fill selection and placement shall recognize the effects of saturation from floodwaters on slope stability, uniform and differential settlement, and scour potential. The minimum elevation of the top of slope for the fill section shall be at the RFD. The minimum distance from any point of the building perimeter to the top of the fill slope shall be either 25 feet or twice the depth of fill at that point, whichever is the greater distance. This requirement does not apply to roadways, driveways, playgrounds, and other related features which are not integral and functional parts of the building proper. Fill slopes for granular materials shall be no steeper than one vertical on one and one-half horizontal, unless substantiating data justifying steeper slopes are submitted to the Building Official and approved. For slopes exposed to flood velocities of less than five feet per second, grass or vine cover, weeds, bushes, and similar

vegetation undergrowth will be considered to provide adequate scour protection. For higher velocities, stone, or rock slope protection shall be provided.

Sec. 612.2.3 Building on Piles or Columns: The building may be constructed above the RFD by supporting it on piles, piers, columns, and in certain cases, walls. Clear spacing of support members, measured perpendicular to the general direction of flood flow shall not be less than eight feet apart at the closest point. The piles or columns shall, as far as practicable, be compact and free from unnecessary appendages which would tend to trap or restrict free passage of debris during a flood. Solid walls, or walled-in columns are permissible if oriented with the longest dimension of the member parallel to the flow. Piles or columns shall be capable of resisting all applied loads as required by "The Building Code" and all applicable flood related loads as required herein. Bracing, where used to provide lateral stability, shall be of a type that causes the least obstruction to the flow and the least potential for trapping floating debris. Foundation supports may be of any approved type capable of resisting all applied loads, such as spread footings, mats, and similar types. In all cases, the effect of submergence of the soil and additional floodwater related loads shall be recognized. The potential of surface scour around the the piles or columns shall be recognized and protective measures provided, as required.

Sec. 612.3 Protection by Dikes, Levees, and Floodwalls: The building shall be considered a flood proofed type when it is protected from floodwaters to the RFD by means of dikes, levees, or floodwalls, either used alone or in combination, as necessary. This protection may extend all around the building where all surrounding ground is low, or on one or more sides where high ground (above the RFD) exists on the remaining sides. Regardless of type and method of construction, dikes, levees, and floodwalls shall be designed and constructed in accordance with recognized and accepted engineering practice and methods. They shall have adequate strength and stability to resist all applied loads and shall provide an effective watertight barrier up to the RFD. According to NFIP regulations, earthen dikes (levees) must be designed to a height of at least 3 feet above the BFE, and even higher in certain other situations. Areas behind dikes not built to provide protection for the Base Flood, including the freeboard requirements, will not be recognized by FEMA as having the level of protection intended by the construction, for purposes of the NFIP. FEMA design, operation, and maintenance criteria for levee systems is set forth in 44 CRF 65.10. If a levee is built according to the provisions in this regulation, the property protected by that levee may be removed from the SFHA.

If the levee or floodwall is a component of the flood proofing of an individual structure, it must be designed such that below the BFE it is watertight, substantially impermeable to the passage of water, and be capable of withstanding hydrodynamic and hydrostatic forces, and the effects of buoyancy. Thought there is no formal requirement for freeboard for levees or floodwalls when used to floodproof an individual structure, it is strongly urged to maintain a freeboard of one foot or greater. The levee or floodwall must, however, protect the nonresidential structure to at least the base flood elevation level. As with other methods of flood proofing nonresidential structures, the levee or floodwall must be designed (or have the design, plans and specifications reviewed) by a registered professional engineer or architect. The design and methods of construction must be certified that they are in accordance with accepted standards of practice for meeting the provisions stated above for being watertight and substantially impermeable to the passage of water.

Sec. 612.3.1 Dikes and Levees: Dikes and levees shall be constructed of suitable selected materials, placed and compacted in layers to a section that has the required stability and impermeability. Prior to start of placement operations, the area on which the dike or levee is to be constructed shall be prepared as required by 612.2.2. In cases where underlying materials are highly pervious, it may be necessary to provide impervious cutoffs. A filter blanket, drainage ditch and/or trench shall be provided along the interior toe of the construction to collect seepage through the dike or levee. All seepage and storm drainage shall be collected at a sump or sumps where it may be pumped out over the dike. Normal surface runoff within and into the diked area during nonflood periods may be discharged through appropriate drainage pipes or culverts through the dike. Such culverts shall have a dependable flap, slide gate, or backflow preventing device which would close either automatically or manually to prevent backflow during a flood. Scour protection measures for dikes and levees shall comply with the requirements of 612.2.2. Clearance from the toe

of the dike or levee to the building shall be a minimum of 20 feet or twice the height of the dike or levee above the interior finished grade, whichever is greater.

Sec. 612.3.2 Floodwalls: Floodwalls may be constructed of concrete, steel sheet piling, or other suitable structural materials. Regardless of type, the wall shall have adequate strength and stability to resist the applied loads. The provisions of 612.3.1 shall be followed, as applicable, regarding removal of unsuitable materials, provision of impervious cutoffs, provision of seepage and storm drains, drainage ditches, sumps and sump pumps, and the minimum clearances from the floodwall to the building. It shall be recognized in the drainage provisions that substantial amounts of leakage may occur through the interlock of a steel sheet piling wall. Adequate expansion and contraction joints shall be provided in the walls. Expansion joints will be provided for all changes in wall direction. Contraction and expansion joints in concrete walls shall be provided with waterstops and joint sealing material both in the stem and in the base. Steel sheet piling walls may be encased in concrete for corrosion protection or shall be coated with a coal tar epoxy coating system and periodically inspected and maintained. Steel sheet piling walls may be used as the impervious core of a dike.